Average values of depth and dye concentration were taken along each transect for each cruise ship from the point where dye values exceeded background levels until they returned to background levels. Plume width measurements were also made using the same points for obtaining average depth and dye concentrations.

Additional samples, above the five planned dye samples, were taken during monitoring operations for the *Paradise* and *Fascination*.

Upon survey completion, the samples were shipped in coolers containing ice to Battelle for final analysis. Before shipping, the sample custody forms were completed and placed in a sealed Ziploc bag that was taped to the inside of the cooler lid. The Battelle Field Custodian, Mr. Tim Kaufman, shipped *in-situ* plume dye samples from Miami and received them at Battelle. He also received sample shipments from the cruise lines for samples collected aboard the cruise ships.

Sample Storage Conditions. Discrete rhodamine dye samples collected aboard the cruise ships were stored chilled at ~ 4ºC. Each cruise ship was provided a shipping cooler and given instructions to store and ship samples on ice. Additional sample storage conditions are presented in Table 5.

Table 5. Analyte, Sampling Method, Volume, Preservation, and Holding Times.

Analyte (Analytical Laboratory)[(a)]	Matrix	Method	Sample Volume	Container Type	Preservation	Holding Time
Laboratory Analyses						
Rhodamine dye (Battelle)	Water	Seapoint RWT Sensor	500 mL	Polyethylene plastic	Cool, ~ 4°C	undetermined
Field Analyses						
Temperature (BDO)	Water	OS200 CTD	NA	NA	NA	*In situ*
Depth (BDO)	Water	OS200 CTD	NA	NA	NA	*In situ*
Transmissometry/ Turbidity (BDO)	Water	Seatech 20-cm (660nm)	NA	NA	NA	*In situ*
Conductivity (BDO)	Water	OS200 CTD	NA	NA	NA	*In situ*

(a) BDO: Battelle Duxbury Operations
NA = Not applicable.

Acoustic Doppler Profiles. Current data from an acoustic Doppler current profiler (ADCP) on board Royal Caribbean Cruise Line's *Explorer* was obtained from NOAA. This data was collected during transit through the site during the plume tracking survey on August 11.

3. Survey Results and Discussion

All plume tracking and sampling operations were successfully completed over the targeted 4-day period (spanning August 10-14) during which four separate cruise ship discharge plumes were continuously monitored and sampled. Numbers of transects conducted and samples collected are presented in Table 4.

Drogues. The initial and final locations for the drogues are shown in Appendix A and listed in Table 6. The figures in Appendix A indicate that the drogues drifted almost due north at an average speed of 7 Km/Hr and distances ranging from 12 to 20 km for the *Fascination* to 30 to 34 km for the *Explorer* and *Paradise* over the three to five hour sampling periods. The fact that the relative positions of the drogues remained the same indicates that the plumes did not break apart in this time frame as the Florida Current was carrying them northward.

Table 6. Locations of Buoy Deployments from Cruise Ships and Retrieval by *Anderson* During Each Plume Tracking Event.

Cruise Ship	Begin Date	Buoy	Activity	Time (24-h)	Latitude (N)	Longitude (W)
Majesty	08-10-01	No data collected				
Explorer	08-11-01	1	Deploy	1943	25°55.697	79°52.697
			Retrieve	Not recovered		
		2	Deploy	1945	26°13.080	79°52.697
			Retrieve	0030	26°13.35	79°51.03
		3	Deploy	1946	25°55.5	79°52.8
			Retrieve	0040	26°12.950	79°51.795
		4	Deploy	1948	25°55.9	79°51.5
			Retrieve	0050	26°12.470	79°52.424
		5	Deploy	1950	25°56.405	79°50.724
			Retrieve	0058	26°11.989	79°52.993
Paradise	08-12-01	1	Deploy	1859	25°38.5	79°51.4
			Retrieve	2350	25°52.8	79°50.0
		2	Deploy	1901	25°38.1	79°50.9
			Retrieve	0000	25°53.8	79°50.7
		3	Deploy	1903	25°37.6	79°50.6
			Retrieve	0010	25°54.1	79°51.6
		4	Deploy	1905	25°37.3	79°50.2
			Retrieve	0020	25°55.2	79°52.3
		5	Deploy	1907	25°36.8	79°49.7
			Retrieve	0027	25°56.3	79°53.1
Fascination	08-13-01	1	Deploy	1910	25°26.70	79°53.55
			Retrieve	2138	25°26.77	79°51.9
		2	Deploy	1914	25°26.39	79°53.39
			Retrieve	2130	25°35.4	79°52.0
		3	Deploy	1916	25°26.09	79°53.30
			Retrieve	2221	25°34.5	79°52.2
		4	Deploy	1918	25°26.81	79°59.37
			Retrieve	2112	25°33.5	79°52.6
		5	Deploy	1921	25°27.09	79°53.34
			Retrieve	2104	25°32.7	79°52.6

[1]Cruise ship time, position, and activity

The order of deployment vs. recovery did reverse during monitoring of activities for both the *Explorer* and *Paradise.* Since the buoys were not labeled prior to deployment, the order of recovery may have been recorded incorrectly. Otherwise the local currents would have to be highly variable which is not evident from the current data provided by NOAA (Figure 6).

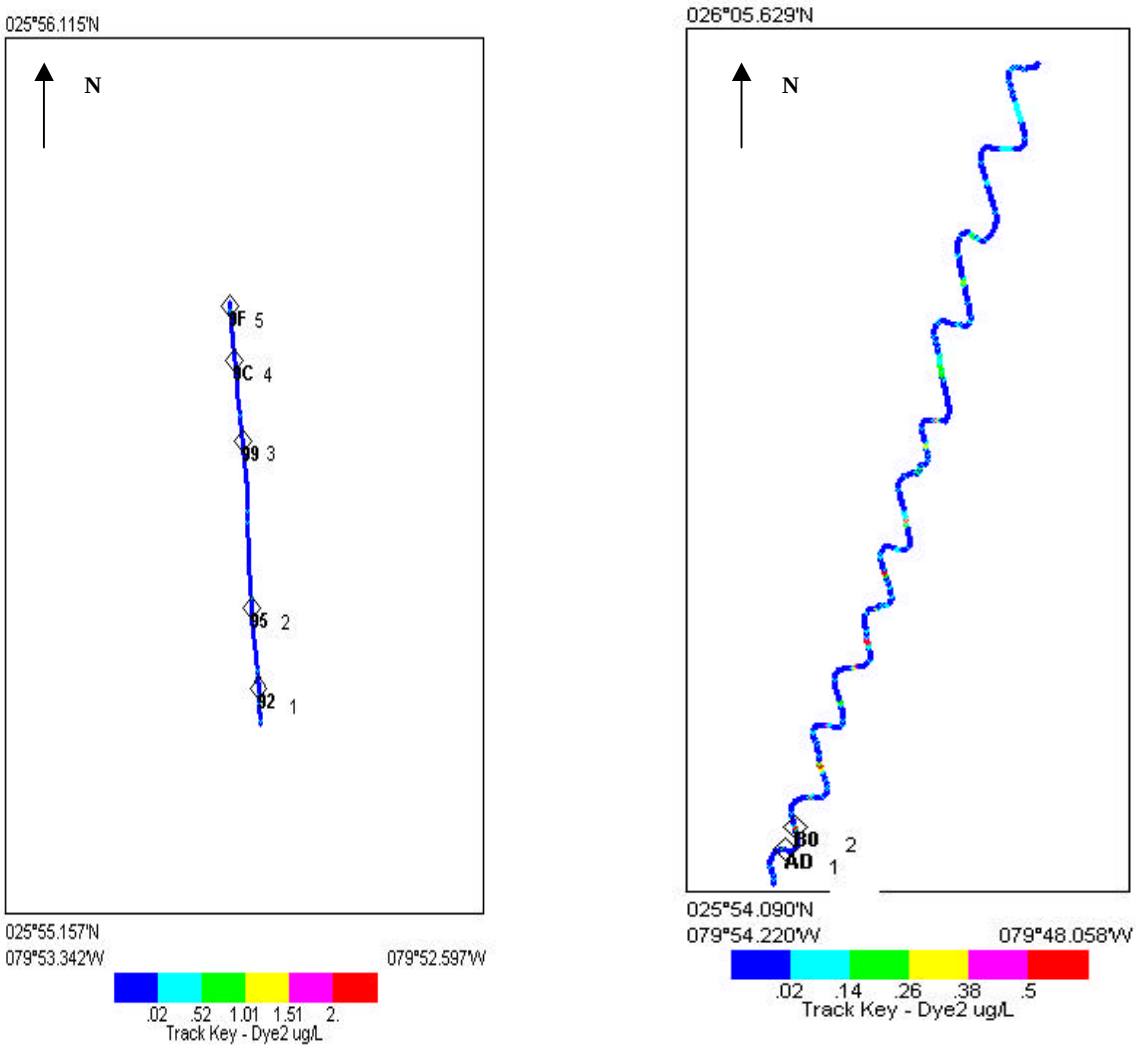
Field Data. All field data (date, time, sampling coordinates, bathymetry, and sample depth) associated with the collection of discrete samples during this survey are presented Appendix B.

Plume Transects, Tracks, and Dye Data. Maps showing the background and survey tracks for each set of plume-tracking events are shown in Figures 2 through 5. Appendix C presents survey tracks and depths for each plume survey. The transect lines are color coded to indicate relative amount of fluorescence and depth of the sensor during a particular transect.

Initial dye concentrations varied considerably depending on the ship and tank specifications at the time of discharge. Table 7 presents several measurements taken during monitoring activities along multiple transects for each cruise ship plume.

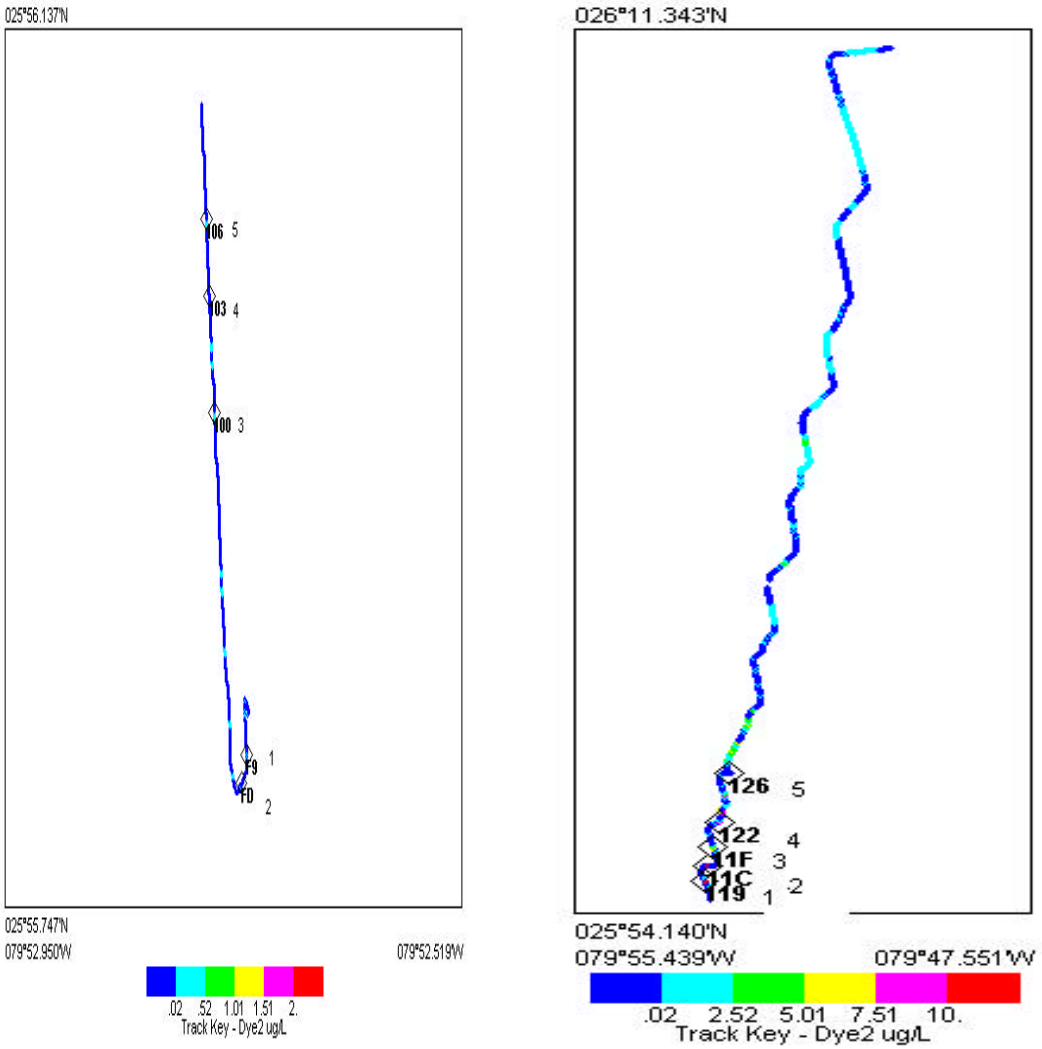
The *Majesty* and *Paradise* discharges exhibited the lowest initial average concentrations of <0.5µg/L. The *Explorer* had the highest initial average concentration exceeding 5µg/L with a maximum of > 36µg/L. The *Fascination* had the second initial highest average concentration >3µg/L with maximum >9µg/L (Table 7).

Time Series Plots and Scatter Plots. Time series plots of dye fluorescence/depth are presented in Appendix D. These plots show the time line of the entire plume survey for each cruise ship and the spikes in dye fluorescence and the transect depth at which the spikes occurred. Appendix E presents the scatter plots of dye fluorescence versus depth. In these plots, the extent of the dye plume relative to depth is evident. These plots were prepared by combining all data files and represent dye concentrations above background levels (0.02 µg/L). All four cruise-ship plumes exhibited high dye concentrations in the surface waters. However for the *Majesty* and *Paradise,* the dye plumes are most concentrated between 5 and 10m, but both plumes penetrate the water column to a depth of approximately 18m. The dye plume of the *Explorer* is very concentrated at the surface and penetrates the water column no deeper than 10 or 12m, possibly because of the propulsion configuration of that vessel. The pattern of the dye-plume scatter plot for the *Fascination* is between the pattern exhibited by the plumes of the *Paradise* and *Explorer*.



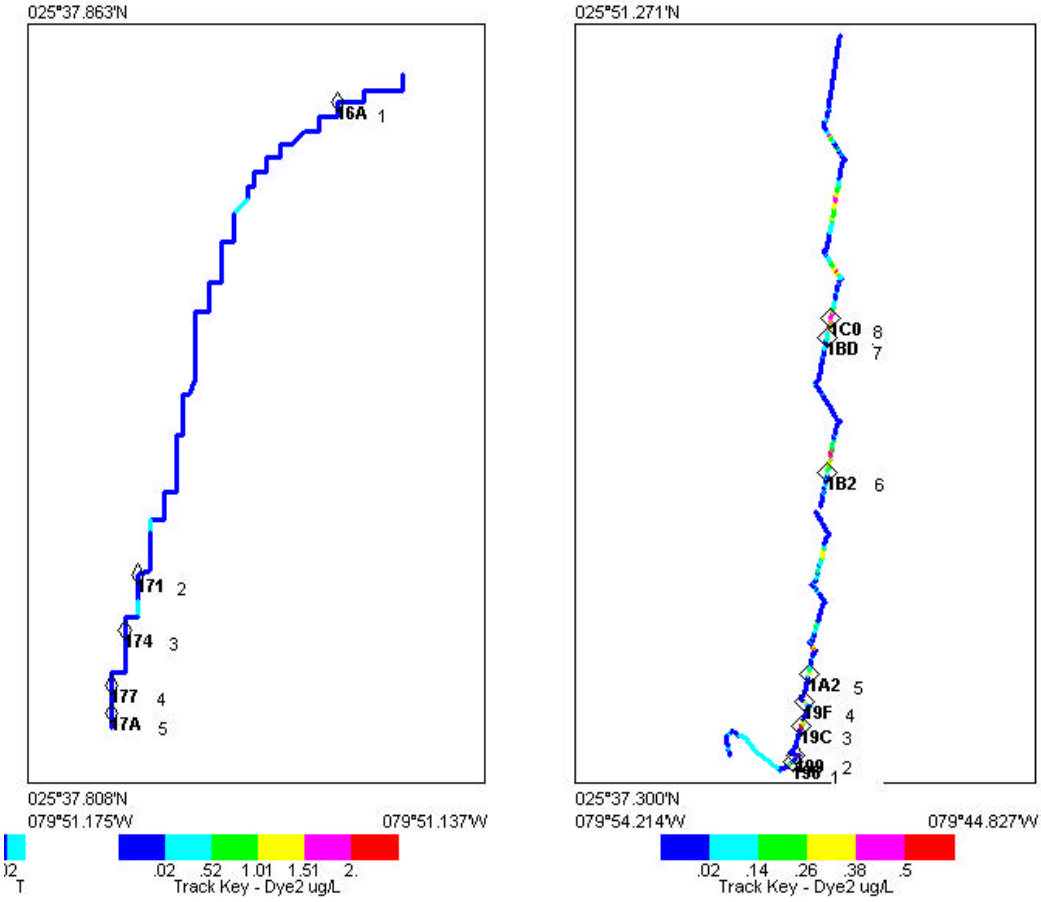
BACKGROUND TRANSECT **IN-PLUME TRANSECTS**

Figure 2. Background and Plume Tracking Transects and Sampling Locations for M/S *Majesty*, August 10, 2001.
(Current had an average speed of ~ 7 Km/ Hr)



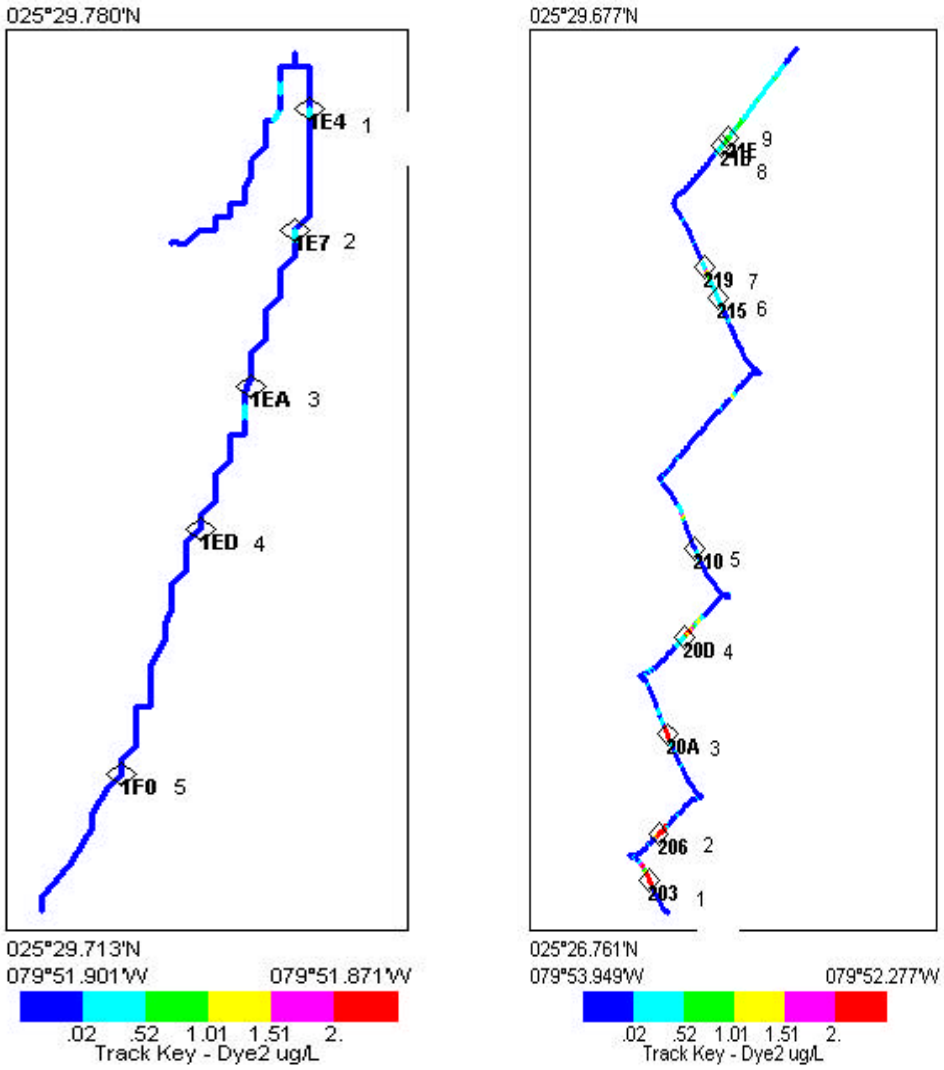
Background Transect **In-plume Transects**

Figure 3. Background and Plume Tracking Transects and Sampling Locations for M/S *Explorer*, August 11, 2001.
(Current had an average speed of ~ 7 Km/ Hr)



Background Transect **In-plume Transects**

Figure 4. Background and Plume Tracking Transects and Sampling Locations for M/S *Paradise*, August 12, 2001.
(Current had an average speed of ~ 7 Km/ Hr)



Background Transect **In-plume Transects**

Figure 5. Background and Plume Tracking Transects and Sampling Locations for M/S *Fascination*, August 13, 2001.
(Current had an average speed of ~ 7 Km/ Hr)

ADCP Data from the M/S Explorer.
Figure 6 shows the current profile structure in the depths ranging from 14 to 44 meters over a four-hour period. These data are provided by the NOAA office located in Miami, Florida. The top segment of Figure 6 shows the depth range from 0 to -44m and the number of pings (ensemble) over time from 0 to ~4.5 hours. The middle and bottom segments of the figure show the direction and magnitude of the currents over the same time period (0 to ~4.5 hours). The date that the data were collected is 8/11/01 (shown as 01/08/11 on the figure); the same day the *Explorer* plume was monitored. The time period of data collection ranged from 22:17 to 02:42 GMT (17:17 to 21:42 EDT) (within the time frame of the plume tracking survey).

The data were taken in 10-meter bins. A bin is a slice of the water column. In this case each slice is 10 meters thick. The top 4 bins are shown (middle and bottom segment of Figure 6): bin 001 (light blue) is centered at -14m, bin 002 (dark blue) is centered at -24m, bin 003 (green) is centered at -34m, and bin 004 (red) is centered at -44m. The course followed by the *Explorer* takes it through the study area and across the Florida Current. The coordinates of the segment extend from 25.78 N latitude, 80.18 W longitude to 26.28N latitude, 78.95 W longitude.

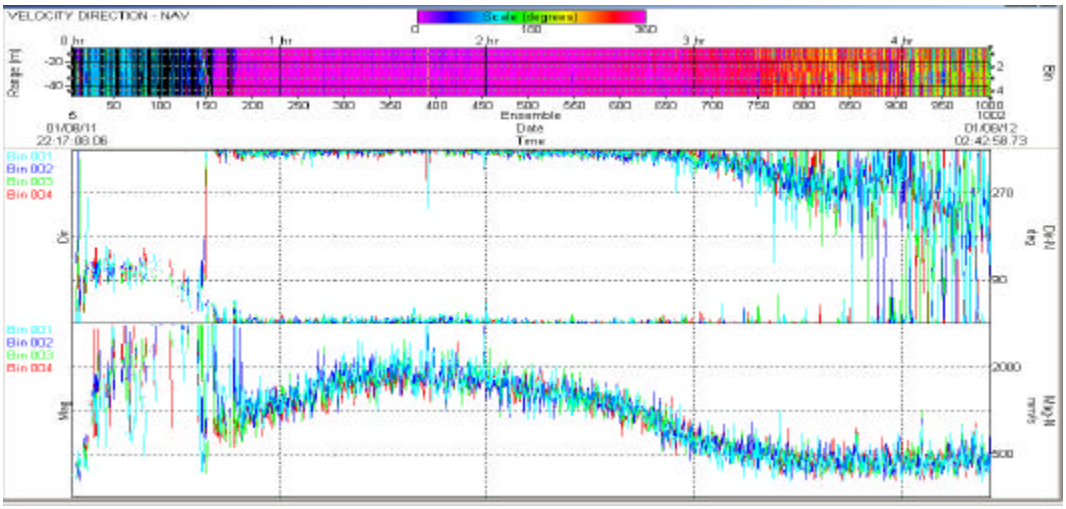


Figure 6. Current Profile Data Taken Aboard the *Explorer* and Provided by the NOAA Office in Miami, Fl

The currents for all depth ranges (bins 001 through 004) are primarily south to north with magnitudes in the range from slightly under 0.5 m/s (~1 Kt.) to nearly 2 m/s (~4 kts.). The currents for all depths match at each location. If shear is present, the direction of one or more of the bins would deviate from the others. This does not occur and currents seem to be uniform over the depths of interest.

Discrete Dye Data. Appendix F contains all the dye data gathered from the discrete samples collected in the cruise ship plumes and collected from the cruise ship tanks. Table F-1 provides

measurements for all samples collected in the cruise ship plumes aboard the *Anderson*. Table F-2 shows discrete sample data collected from the specified cruise ship tanks. It also provides the amount of dye added to the tanks as well as the average measured dye concentrations based on measurements of dye fluorescence from discrete tank samples taken for each cruise ship.

Plume Dilution. Dye concentrations after discharge were measured above background behind every plume. Measured concentrations were lower than calculated concentrations (see Appendix H) except for the *Explorer* and *Paradise*, indicating that initial dilutions are greater than anticipated. Initial dye dilution estimates both calculated and measured were made after discharge. These estimates exceeded dilutions of 100,000:1 and in some cases exceeded 600,000:1 (Table 8 and Appendix G). The calculated estimates were made from tank dye concentration calculations and plume volume estimates based on length, width, and depth of the plume at T=0. The measured estimates are based on fluorescense measurements from tank samples and direct plume measurements (Table 8). In general, dye concentrations generally decreased over time and with depth (Table 7).

Table 7. Average Dye Concentrations in Each Transect for Each Cruise Ship.

Pass	Date	Time	Depth of tow (m)		Estimated Plume Width (m)	Dye Concentration (µg/L)			Filename
			Average	Std. Dev.		Average	Maximum	Std. Dev.	
Cruise Ship: *Majesty*									
1	10-Aug-01	18:48	1.92	0.09	66	0.35	1.08	0.37	W23PT059-00137.Pat
2	10-Aug-01	18:53	5.07	0.06	26	0.42	0.86	0.32	W23PT059-00256.Pat
3	10-Aug-01	18:58	7.89	0.05	75	0.31	1.10	0.36	W23PT059-00401.Pat
4	10-Aug-01	19:04	6.67	5.51	66	0.29	0.93	0.27	W23PT059-00553.Pat
5	10-Aug-01	19:14	2.24	0.08	137	0.20	0.62	0.16	W23PT060-00049.Pat
6	10-Aug-01	19:20	5.11	0.19	37	0.18	0.36	0.11	W23PT060-00190.Pat
7	10-Aug-01	19:27	8.73	0.08	125	0.26	0.51	0.17	W23PT060-00378.Pat
8	10-Aug-01	19:32	11.77	7.80	66	0.29	1.22	0.39	W23PT060-00503.Pat
9	10-Aug-01	19:40	3.40	1.67	300	0.11	1.13	0.23	W23PT060-00708.Pat
10	10-Aug-01	19:48	2.12	0.03	48	0.37	0.72	0.25	W23PT060-00925.Pat
11	10-Aug-01	19:54	5.19	0.02	95	0.27	1.07	0.36	W23PT060-01084.Pat
12	10-Aug-01	20:00	8.33	0.16	76	0.18	0.67	0.17	W23PT060-01230.Pat
13	10-Aug-01	20:11	6.82	7.68	124	0.07	0.34	0.07	W23PT061-00206.Pat
14	10-Aug-01	20:18	2.07	0.03	35	0.19	0.36	0.13	W23PT061-00393.Pat
15	10-Aug-01	20:23	4.38	0.04	92	0.39	0.98	0.30	W23PT061-00528.Pat
16	10-Aug-01	20:32	8.88	0.08	114	0.12	0.25	0.07	W23PT062-00129.Pat
17	10-Aug-01	20:45	10.38	0.06	67	0.21	0.61	0.21	W23PT062-00462.Pat
18	10-Aug-01	20:53	12.03	0.03	40	0.18	0.40	0.12	W23PT062-00661.Pat
19	10-Aug-01	21:01	14.26	0.06	111	0.09	0.29	0.08	W23PT062-00888.Pat
20	10-Aug-01	21:12	17.41	0.07	30	0.04	0.07	0.02	W23PT063-00001.Pat
21	10-Aug-01	21:21	2.17	0.06	298	0.06	0.15	0.03	W23PT063-00241.Pat
22	10-Aug-01	21:31	5.28	0.02	124	0.06	0.10	0.03	W23PT063-00498.Pat
23	10-Aug-01	21:39	8.82	0.17	202	0.02	0.10	0.02	W23PT063-00709.Pat
Cruise Ship: *Explorer*									
1	11-Aug-01	19:44	1.95	0.11	147	5.13	36.15	10.02	W23PT087-00080.Pat
2	11-Aug-01	19:48	4.04	0.83	157	3.08	17.56	5.06	W23PT087-00176.Pat
3	11-Aug-01	19:54	7.54	0.22	86	3.02	9.81	3.20	W23PT087-00339.Pat

Pass	Date	Time	Depth of tow (m)		Estimated Plume Width (m)	Dye Concentration (µg/L)			Filename
			Average	Std. Dev.		Average	Maximum	Std. Dev.	
4	11-Aug-01	20:01	5.35	6.61	144	1.93	10.77	3.19	W23PT087-00506.Pat
5	11-Aug-01	20:07	4.05	4.18	53	4.30	8.89	3.62	W23PT087-00662.Pat
6	11-Aug-01	20:11	2.24	0.03	59	5.46	20.79	6.99	W23PT087-00769.Pat
7	11-Aug-01	20:22	2.51	0.38	69	0.85	3.56	1.17	W23PT088-00207.Pat
8	11-Aug-01	20:25	1.66	1.61	279	2.98	8.54	1.85	W23PT089-00001.Pat
9	11-Aug-01	20:30	3.89	3.35	293	2.56	8.07	2.49	W23PT089-00152.Pat
10	11-Aug-01	21:02	2.59	0.10	67	0.56	2.01	0.58	W23PT089-00972.Pat
11	11-Aug-01	21:05	2.84	0.06	48	2.11	3.59	0.76	W23PT090-00001.Pat
12	11-Aug-01	21:19	6.82	0.57	102	2.28	4.27	1.29	W23PT091-00199.Pat
13	11-Aug-01	21:42	3.98	3.61	119	1.19	4.86	0.94	W23PT092-00198.Pat
14	11-Aug-01	22:05	2.29	0.05	104	1.69	3.08	0.93	W23PT093-00194.Pat
15	11-Aug-01	22:08	2.29	0.06	122	0.50	0.82	0.18	W23PT094-00001.Pat
16	11-Aug-01	22:20	4.58	3.11	68	0.68	1.54	0.55	W23PT095-00133.Pat
17	11-Aug-01	23:00	1.78	0.08	125	1.40	1.94	0.26	W23PT096-00001.Pat
18	11-Aug-01	23:26	5.03	0.04	574	0.38	1.88	0.24	W23PT097-00421.Pat
19	11-Aug-01	23:54	1.87	1.06	909	0.36	1.12	0.24	W23PT098Z-00196.pat
Cruise Ship: *Paradise*									
1	12-Aug-01	19:19	2.11	0.07	182	0.08	0.42	0.10	W23PT119-00066.Pat
2	12-Aug-01	19:24	8.40	0.13	76	0.42	1.28	0.47	W23PT119-00199.Pat
3	12-Aug-01	19:34	9.66	1.09	93	0.41	0.96	0.31	W23PT120-00225.Pat
4	12-Aug-01	19:43	12.62	0.24	57	0.17	0.48	0.15	W23PT120-00457.Pat
5	12-Aug-01	19:54	13.63	0.20	84	0.14	0.34	0.09	W23PT120-00737.Pat
6	12-Aug-01	20:04	4.61	0.50	143	0.39	1.31	0.38	W23PT121-00084.Pat
7	12-Aug-01	20:12	15.54	0.47	109	0.08	0.25	0.06	W23PT122-00040.Pat
8	12-Aug-01	20:26	17.93	0.28	64	0.09	0.31	0.08	W23PT122-00392.Pat
9	12-Aug-01	20:34	2.11	0.12	274	0.12	0.38	0.11	W23PT122-00595.Pat
10	12-Aug-01	20:44	16.28	7.12	296	0.02	0.37	0.03	W23PT123.Pat
11	12-Aug-01	21:04	5.11	0.14	305	0.21	0.62	0.15	W23PT125-00104.Pat
12	12-Aug-01	21:16	15.23	6.39	580	0.01	0.11	0.01	W23PT126.Pat
13	12-Aug-01	21:48	7.97	0.06	341	0.21	0.67	0.17	W23PT128-00165.Pat
14	12-Aug-01	22:05	2.07	0.21	455	0.21	0.56	0.15	W23PT129-00090.Pat
15	12-Aug-01	22:23	5.20	0.31	210	0.18	0.36	0.11	W23PT130-00081.Pat
16	12-Aug-01	22:30	5.06	0.52	135	0.22	0.47	0.13	W23PT131-00001.Pat
17	12-Aug-01	22:44	8.16	0.26	480	0.11	0.50	0.12	W23PT131-00365.Pat
Cruise Ship: *Fascination*									
1	13-Aug-01	19:29	2.30	0.13	88	3.40	8.65	2.66	W23PT149-00042.Pat
2	13-Aug-01	19:34	4.70	0.07	84	3.80	8.52	2.58	W23PT149-00188.Pat
3	13-Aug-01	19:42	8.23	0.11	87	2.27	9.40	3.12	W23PT149-00390.Pat
4	13-Aug-01	19:51	12.07	0.17	189	1.08	4.89	1.22	W23PT149-00625.Pat
5	13-Aug-01	20:02	7.53	5.88	54	0.31	2.74	0.67	W23PT149-00896.Pat
6	13-Aug-01	20:20	2.52	0.12	174	0.30	1.80	0.45	W23PT150-00168.Pat
7	13-Aug-01	20:34	8.35	0.17	471	0.36	0.94	0.20	W23PT151-00245.Pat

Table 8. Calculated and Measured Dye Concentrations and Dilutions for Each of the Four Cruise Ships.

	Parameter	Vessel			
		Majesty	***Explorer***	***Paradise***	***Fascination***
Calculated Values	Dye - v (L)/ wt.(kg)	114/22.6	133/26.4	133/26.4	137/27.1
	Volume of water + dye in tank (L)	113,114	18,300	108,133	27,137
	Tank Concentration (g/L)	0.1998	1.443	0.244	0.999
	Dye discharged (kg)	21,201	24,669	16,635	24103
	Calculated Plume Volume (L)	36,302,904,000	15,517,320,000	45,503,640,000	6,172,100,000
	Calculated plume concentration (g/L)	5.84E-07	1.59E-06	3.66E-07	3.91E-06
	Calculated Dilution	**342,123:1**	**907,547:1**	**666,667:1**	**255,499:1**
Measured Values	Measured Tank Concentration (g/L)	0.13,512	1.002	0.2704	0.9806
	Measured Plume Concentration (g/L)	3.50E-07	5.13E-06	4.20E-07	3.40E-06
	Measured Dilution	**386057:1**	**195,322:1**	**643,810:1**	**288,412:1**

4. Findings and Conclusions

The August 2001 plume tracking survey was designed to provide field data on the cruise ship discharge (effluent) plume characteristics in offshore waters, and provide information on whether or not the cruise ship blackwater or graywater discharge-plumes behave as predicted by a model developed for Alaska waters (Colonell *et al*. 2000)[2].

Based on the Alaska model, effluent discharges from cruise ships were expected to undergo an initial dilution of approximately 40,000:1. Colonell *et al*. (2000)[2] defines initial dilution as the physical mixing of a relatively small and moving discharge entering the water body and secondary dilutions as caused by mixing by the ship propellers. In this plume and tracking report, initial and secondary are not distinguished, but are called initial dilution.

The following findings for each ship were:

M/S Majesty

Calculated dilution: 342,000:1
Measured dilution: 386,000:1

M/S Explorer

Calculated dilution: 908,000:1
Measured dilution: 195,000:1

[2] Colonell, JM, SV Smith, and RB Spies. 2000. Cruise Ship Wastewater Discharge into Alaskan Coastal Waters. Alaska SeaLife Center Technical Report Number 2000-01. 48pp.